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Research paper



Abrasion Resistance of Gabion Wires Against Simulated Weathering and Field Conditions

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Abstract

Gabions are steel wire mesh cages filled with stones of appropriate size and mechanical characteristics. It is widely applied in geotechnical and hydraulic engineering as retaining and erosion control structures. Therefore, it must be made of durable materials to withstand most of the site conditions and weathering. Various coating technologies has been applied to enhance the lifespan. This study was conducted to examine the effect of moisture, acid, alkaline and saltwater under ultraviolet radiation and heat on the durability of a plastic-based coating material used as protective coating of gabion wires. Exposure conditions were simulated via natural weathering method, where they were placed outdoors at a designated test station. The samples were soaked and covered in soil to represent applications in waterlogged as well as buried / semi-buried field conditions. The weathered samples were subjected to the abrasion test after different periods of exposure over 250, 500 and 750 hours. 3 samples each were tested to maintain consistency in the measurements taken. Degradation of the coating material due to the simulated weathering conditions varied in terms of rate and severity, though the overall results indicate alkalinity to be more detrimental than acidity and salinity. Variation among the samples' degradation was observed to be more distinct in the terms of soaked and soil-covered conditions. In conclusion, samples buried in alkali-tainted soil are the least durable against abrasion as the recorded mass loss percentage was the highest, followed by acid-soaked samples. Some plausible explanations include the lack of heat built up on seawater-soaked samples leading to less degradation, and surfacial biofouling of soaked samples serving as a protection against UV light or chemical attack. Further work is in the pipeline to examine the effects of longer exposure period and wider range of exposure conditions to verify the coating material's long-term performance.

Keywords: *Gabions; Natural Weathering; PVC; Abrasion Resistance; Organic Coating.*

1. Introduction

Gabions, rectangular large cages or baskets made of either steel wire or square welded mesh and usually filled with stones are one of the most essential elements in the geotechnical field for their versatility and strength in slope stabilization, closing of river banks, road construction, landslide consolidation and hilly terrain reclamation [1].

The steel wires of the gabions are treated with various anti-corrosion materials such as plastic coating, zinc-aluminium alloy and heavy zinc coating to provide extra durability [2]. However, since gabions are used for various purposes, they are constantly under different exposure conditions. The effectiveness and durability of the protective coating may vary due to the different environment.

The objectives of this study are to determine the anti-corrosion characteristics of a proprietary plastic-based coating material for gabion steel wire and to identify the rate of corrosion under various weathering conditions in dry and soaked conditions. Study was conducted to examine the effectiveness of a proprietary plastic-based protective coating for gabion wires against corrosion in exposure to weathering elements. Material is based on the Industrial Collaborator, i.e. United Glory Industry Sdn. Bhd, Batu Pahat recommendation and supply. Weathering elements examined include UV exposure and heat in both dry and soaked conditions. The effectiveness of the protecting coating would be determined by abrasion resistance tests. Material samples are subjected to natural weathering for 750 hours

2. Literature Review

Gabions can be applied in both civil and hydraulic engineering, it implies that gabions will be found in or on soil as retaining structures, along the streams and sea coast as erosion control structures. With such wide applications, the gabions must be built durable enough to withstand all possible site conditions that might weaken and damage the structure. However, the durability of the gabions relies greatly on the durability of the wire mesh as limited life of the wire basket is the major drawback of gabions [3]. To overcome, present coating technology which applies a polyvinyl chloride (PVC) or cross-linked polyethylene (XLPE) guaranteed the durability of gabions [2].

Gabions can be formed by hexagonal woven wire mesh or welded wire mesh. For wire mesh, the materials must satisfy high mechanical properties and corrosive resistance. Galvanized wires are normally used to reduce corrosion. The wires may be also coated with PVC or other materials to prevent corrosion which can damage the wire mesh [4]. When individual units are stacked, it forms a reinforced cellular structure, known as gabions wall.

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Coatings play a significant role in corrosion control which are later applied in major corrosion-control methods include sacrificial protection and barrier protection, but very often they are used in conjunction [5]. Sacrificial protection, cathodic protection or zinc-rich coating is a method to prevent corrosion galvanically. In contrast, barrier protection is usually applied in the form of impermeable coatings to suppress the transmission of oxygen and water from contacting the metal surface, to a sufficient extend that corrosion may be prevented [6].

Weathering is a universal phenomenon that occurred in plastic materials when they are subjected to external environments and exposed to the outdoor thermal, radiation moisture and chemical conditions [7]. The effects of weathering can be shown in various forms including change in colour, texture and dimensions, weakening of molecular chains, altering the mechanical, electrical and physical properties. Worse, weathering may cause materials to completely deteriorate. Weathering factors include heat, light, oxygen, water/humidity and pollutants [8].

Weathering test is a scientific process of exposing polymeric materials to a natural environment or accelerated in a weathering chamber. Weathering techniques generally involve comparative technique which expose materials together with a benchmark material of known performance or measure the change in properties of an exposed material [7]. Weathering test is a variable science as the weather is variable, hence the exposed materials are facing constant change of environment [7].

3. Methods and Materials

In this study, the focus is on adopting natural/outdoor weathering testing to determine the effect of weathering on the proprietary plastic-based coating by evaluating their mechanical properties change. The mechanical properties evaluated is abrasion resistance. Figure 1 shows the overall research methodology flow chart of this research.

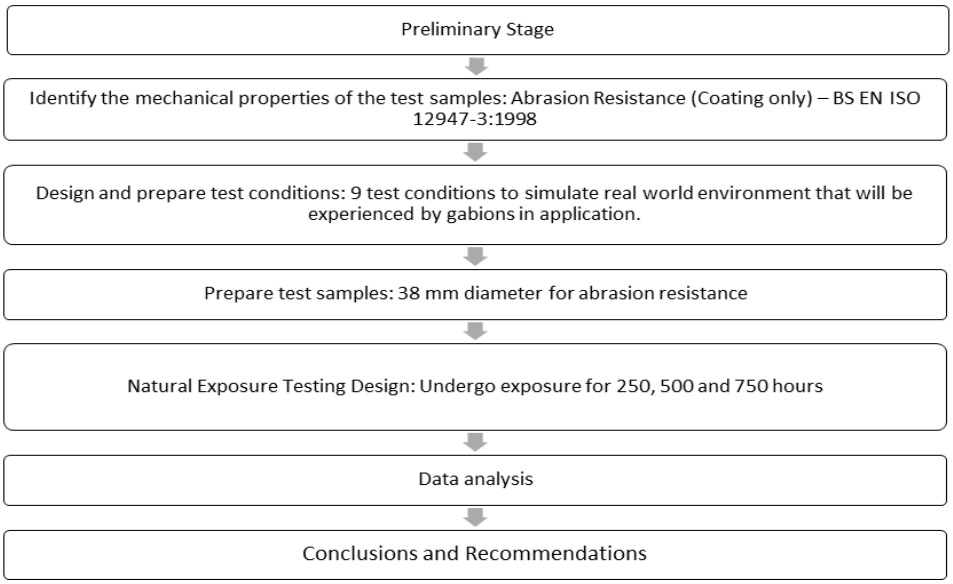

Fig. 1: Overall research methodology flow chart of this research

Site conditions refer to the natural environment that might be experienced by the gabions during their applications. The proposed site conditions included the exposure possibilities, recreated in outdoor condition to examine how these conditions affect the weathering rate of the protective coating. Table 1 shows how the proposed conditions were related to real conditions.

Table 1: Relationship between prepared conditions and actual site conditions

No.	Proposed Site Conditions	Simulation
1.	Unconditioned	Typical daytime
2	Soaked in water	Applied in river banks, dams and flood prone areas
3	Soaked in acid (pH 4.5)	Applied in contaminated rivers, peat soil area
4	Soaked in alkali (pH 8.0)	Applied in contaminated rivers near industrial area
5	Soaked in saltwater	Applied in coastal area
6	Covered with wet soil	Buried in normal river area
7	Covered with acidic soil (pH 4.5)	Buried in peat soil area
8	Covered with alkali soil (pH 8.0)	Buried in alkali metal polluted soil
9	Covered with marine deposits	Buried in coastal area

The test samples of proprietary plastic-based coating were provided by United Glory Industry UGI Sdn. Bhd. The geometry and dimension of the test samples were based on the mechanical properties testing carried out after every 250 hours of exposure for total of 750 hours. Each test required samples of specific dimensions to be installed in the test equipment. The abrasion resistance was determined using the textile abrasion tester as described in BS EN ISO 12947-3:1998. The proprietary plastic-based coating for abrasion resistance samples were manufactured using milling method. The average thickness of the sheet is 1.40 mm. The test samples were cut into circular shape with diameter of 38 mm using a sample cutter (Fig. 2).



Fig. 2: Geometry and dimensions of the abrasion resistance samples

The outdoor weathering test adopted the direct exposure method, which was conducted by exposing test samples on an exposure rack. The test samples were subjected to elements of natural outdoor environment, which primarily included solar radiation (UV), moisture and heat. The test was carried out for 750 hours, starting from 22nd October 2017 to 25th November 2017, with samples

retrieved for tests every 250 hours to run the abrasion resistance test.

The outdoor weathering test was conducted on an empty field located in between Block F and Block G in Universiti Tun Hussein Onn Malaysia (UTHM) Pagoh Campus (2.149N, 102.731E) as shown in Fig. 3 and 4. The testing site was an open field and received sunlight throughout the day without obstruction by nearby structures. The climatic data were monitored.



Fig. 3: Test site

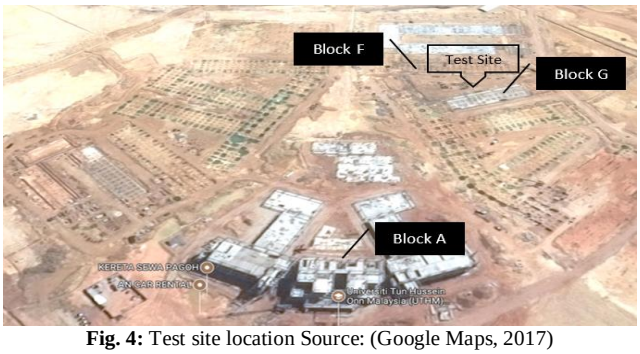

Fig. 4: Test site location Source: (Google Maps, 2017)

A steel exposure rack was fabricated to hold the test samples throughout the exposure period. The rack was designed to be tilted with exposure angle of 45° from the horizontal (Fig. 5).

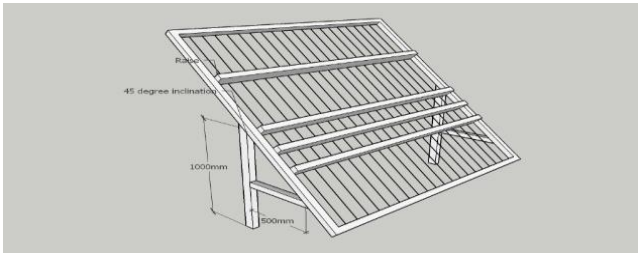

Fig. 5: Design of exposure rack (SketchUp Drawing)

In the set-up, monitoring systems were included to observe and record the changes in the variables during the weathering test. The ambient temperature and relative humidity of the test site were measured and recorded automatically by Elitech GSP-6 Temperature and Humidity Data Logger. The rainfall intensity was monitored daily by ClimeMET CM1088 Rain Gauge and data were recorded in the ClimeMET CM5011 Rainfall Chart. Complete set-up was shown in Fig. 6.

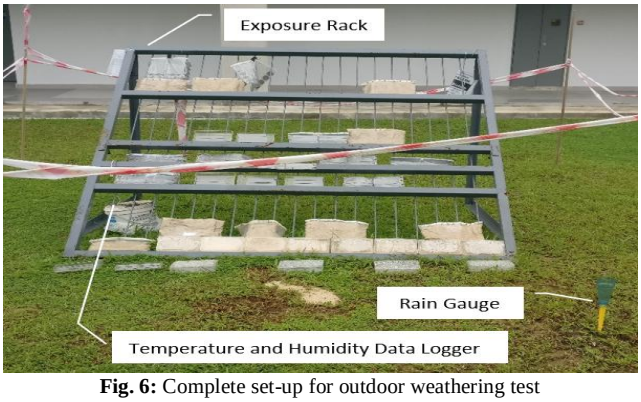

Fig. 6: Complete set-up for outdoor weathering test

During weathering, samples were placed on the rack to receive maximum exposure to UV, heat and moisture. All 9 exposure conditions were simulated in separate sample holders to avoid cross-contamination of acidic, alkaline and salt solution vapours.

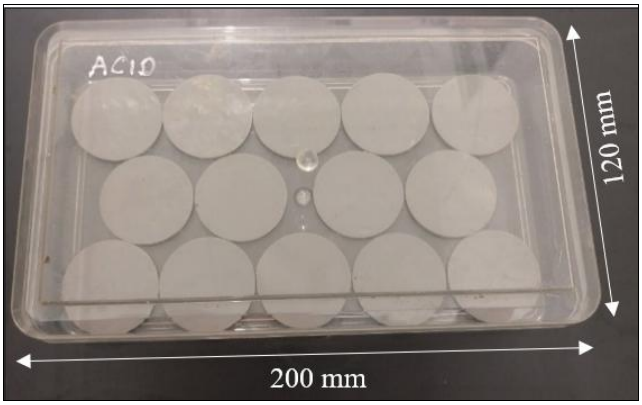

Fig. 7: Abrasion resistance samples

Abrasion resistance samples are placed in clear acrylic container (200 mm X 120 mm X 35 mm) (Fig. 7). The container was chemical resistant and provided with clear cover to minimize the contamination of site conditions. Samples were arranged to prevent any overlapping and to maximize the exposure area.

A set of test samples were tested for abrasion resistance without undergoing any exposure test, i.e. control samples. This was to provide the base results for comparison with the exposed test samples. Abrasive resistance is a test carried out to assess the mass loss from the surface of the coating materials when abraded against an abradant. This test was carried out according to BS EN ISO 12947-3:1998 using a Shirley Developments Abrasion Tester Mark III. Modification was done to replace the fabric sample with coating material and the fabric abradant with abrasive paper (Fig. 8 and 9).

The test samples were weighed to obtain the original mass to 0.01 g accuracy. The circular test samples were then mounted on the sample holders and subjected to 12 kPa top weight. The circular abradants of 140 mm diameter 280-grit silica carbide abrasive papers were mounted in the abradant holders. The test samples were subjected to 1000 rubs against the abrasive medium in a translational movement, tracing a Lissajous figure. The sample holder rotated freely around its own axis perpendicular to the plane of the test sample. The abradant was replaced after every 1000 rubs.



Fig. 8: Abrasion resistance set-up (Without cover)

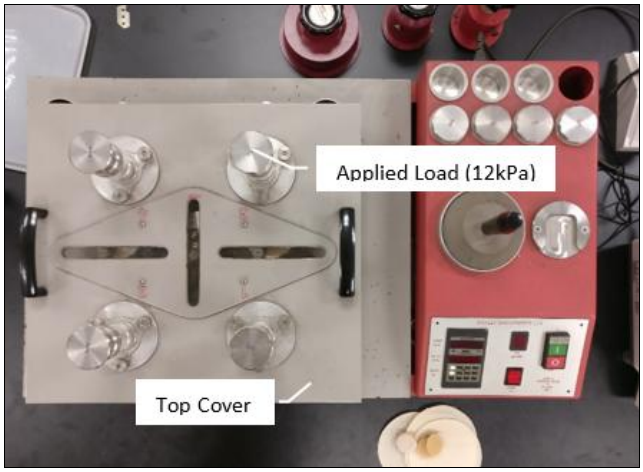

Fig. 9: Abrasion resistance set-up (With cover)

4. Results and Discussion

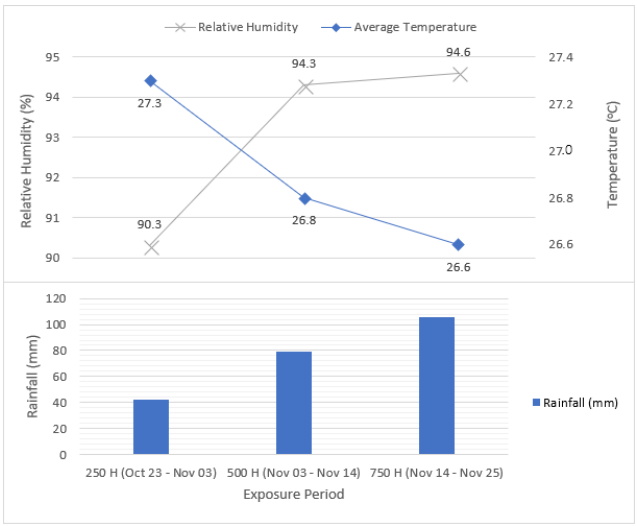

Fig. 10: Average temperature, relative humidity and total rainfall for the exposure site.

Climatic parameters monitored throughout the natural weathering included ambient temperature, relative humidity and rainfall intensity. All parameters were monitored from 23th October 2017, 9.00 a.m.to 25th October 2017, 9.00 a.m. Samples are being tested for the change in abrasion resistance and tensile properties according to modified BS EN ISO 12947-3:1998 and EN ISO 527-3:1995 respectively every 250 hours interval. The test results were compared between the control (unexposed) and the exposed samples. This helps to understand how each site conditions and natural weathering can affect the durability of the PVC coating material. The meteorological data obtained during the weathering period summarized and illustrated in Fig 10.

All exposed samples were retrieved from the test site in every 250 hours interval and tested for changes in mechnical properties (abrasion resistance). The durability of PVC coating against various site conditions and weathering were evaluated by comparing the exposed samples against the unexposed (control sample).

Coating material with abrasion resistance is described as the ability to protect substrates from wear by friction, hence protecting the aesthetic appearance and durability under constant use. Therefore, the less wear mass loss indicates better abrasion resistance. Mass loss percentage was calculated using Equation 1.

Mass loss percentage =

$$[(final\ mass - initial\ mass) / (Initial\ mass)] \times 100 \quad (1)$$

The percentage of mass loss of PVC coating samples upon 1000 rubs against 280 grit abrasive paper for soaked and buried samples are shown in Fig 11 and Fig 12 respectively. The percentage of mass loss showed variations from 250 H to 750 H for both soaked and buried samples.

Comparing the soaked, unconditioned samples and control, the unconditioned samples, samples in acid and seawater generally showed an increase in mass loss percentage. Samples in water showed an increase from 250 H to 500 H and experience fall from 500 H to 750 H whereas samples in alkali decreased steadily across 750 H.

For buried samples, the results showed similar variation as in soaked samples. Samples in alkali and acid showed continuous decrease in mass loss percentage whereas samples in seawater showed increase from 250 H to 500 H and decreased from 500 H to 750 H. Only samples in water showed continuous increase in mass loss percentage across 750 H.

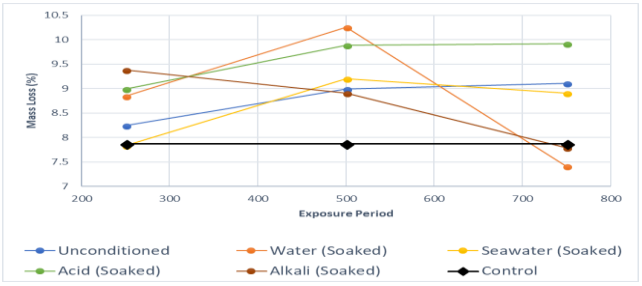

Fig. 11: Comparison of mass loss percentage among soaked samples subjected to different site conditions across 750 exposure hours

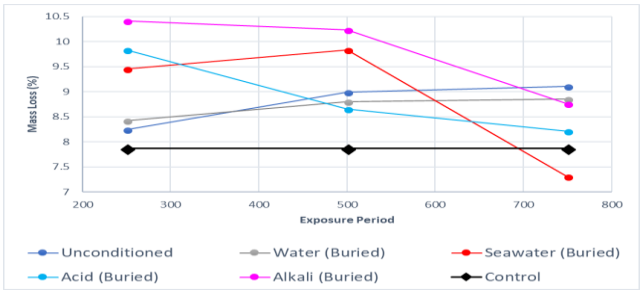

Fig. 12: Comparison of mass loss percentage among buried samples subjected to different site conditions across 750 exposure hours

750 hours of outdoor exposure may not be significant compared to 2500 hours of accelerated UVA exposure or 4000 hours of accelerated Xenon Arc exposure as required in BS EN 10223-3:2013 for organic coated gabions. Hence, the mass loss percentage across 750 exposure hours was averaged and shown in Fig. 15 to understand which site conditions have the most effect on the abrasion resistance of PVC coating.

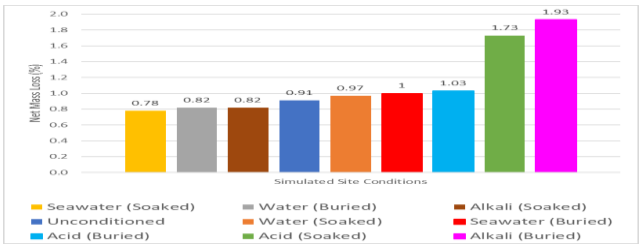

Fig. 13: Net mass loss percentage of different samples

The relatively lower mass loss percentage shown in seawater, alkali and water (soaked) might due to the lack of heat build-up in samples and biofouling of sample surface [9]. Samples exposed to sunlight undergo heat build-up which results in the samples reaching significantly higher temperature than the surrounding air. When air temperature around 26ºC to 36ºC during the period of exposure, the samples' surface can be much higher, as much as

60ºC than that of the surrounding air. The study also mentioned all materials exposed to the sea undergo fouling. Fouling leads to the formation of biofilm which encourage algal growth. Ultimately, the biofilm becomes opaque and restrict light availability for photo-oxidation to occur. Samples subjected to acidic condition show relatively higher in mass loss percentage may due to the lack of biofilm formation as optimum pH range for most cultured algae species is between 7 to 9, optimum range is 8.2 to 8.7 [10]. Therefore, algae growth may be prohibited under low pH condition (4.5). Buried samples generally showed higher mass loss percentage compared to soaked samples. This may due to the higher temperature of sand compared to water when exposed to sunlight as the specific heat capacity of sand is significantly lower than water, 800 J kg-1K-1 compared to 4200 J kg-1K-1. Hence, temperature of sand is relatively easier to raise compared to water, resulting in samples exposed to higher temperature during daytime and lower during non-daytime (greater temperature change cycle). Samples buried in alkali showed the greatest mass loss percentage might due to the above-mentioned factor. PVC under environmental stress crazing conditions was found to have significantly affected in high pH sodium hydroxide (NaOH) solution [11].

5. Conclusion

The overall durability of the PVC coating was determined as most durable when unconditioned and least durable in acid-soaked. Despite the short weathering period (32 days of natural weathering), all samples had showed degradation in abrasion resistance. The data obtained did not show the 'ideal' trend of degradation due to external factors such as weather, biological influences and pollutants.

The lack of heat built up on seawater soaked-samples helped to reduce the impact of degradation on the samples surface. Besides, biofouling of soaked samples surface appeared to be a barrier to protect against surface degradation by UV and chemical attack. In further studies, samples should undergo longer hours of exposure to weathering, i.e. 2 years to show more significant changes in mechanical properties. Short exposure period may lead to fluctuation in mechanical properties due reaction such as cross-linking of polymer. Besides, evaluation on the durability of coating materials should be conducted on coated substrate to show more realistic representation of the coating material under actual applications.

Acknowledgement

Appreciation goes to Universiti Tun Hussein Onn Malaysia who provided the test area, laboratories and necessary resources throughout the study. Besides, Ms. June Lau from Syarikat Nam Ah Sdn. Bhd who is willing to provide technical support and knowledge on polymer testing.

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